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HUMAN COGNITIVE ENHANCEMENT  
ETHICAL IMPLICATIONS FOR AIRMAN-MACHINE TEAMING

by

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## **Biography**

Lieutenant Colonel William M. Curlin enlisted in the United States Air Force in 1984 and received his commission through the Air Force Officer Training School in 1996. Colonel Curlin is a career Air Force acquisition officer and a member of the Department of Defense Acquisition Corps. He has held program management positions at two Air Force Material Command product centers developing cyber network defensive systems, air combat training systems, and miniature smart munitions. In 2000, Colonel Curlin completed the Air Force Institute of Technology Education with Industry program at Lockheed Martin, Owego, New York. He led developmental flight test programs supporting United States Special Operations Command and Air Force Special Operations Command. He served in the Pentagon on Air Staff as a program element monitor in the Office of the Secretary of the Air Force for Acquisition and as a legislative liaison for budget and appropriation matters in the Office of the Undersecretary of Defense (Comptroller). In 2009, Colonel Curlin completed in-residence intermediate developmental education as an Air Force Legislative Fellow with the United States Senate and in 2010 attended joint professional military education (phase II) at the Joint Forces Staff College. Colonel Curlin was assigned to a joint tour assignment at Headquarters United States Central Command as Chief of Congressional Engagements, and subsequently served as the Headquarters Commandant and Commander, Air Force Element Squadron. Colonel Curlin completed a second squadron-level command tour as a Materiel Leader with the Defense Contract Management Agency at Northrop Grumman, Linthicum, Maryland. He holds a Bachelor and Master degrees in business and is a fully qualified joint officer and level III acquisition professional. Colonel Curlin is currently an in-residence senior development education student at the United States Air Force Air War College, Maxwell Air Force Base, Alabama.

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## Abstract

Advancements in human brain research and neuroscience offer great promise for future joint warfighting capabilities. As the national security environment grows in complexity, weapon system designs must advance to provide United States joint warfighters with capabilities to counter increasingly challenging adversarial threats. It is hypothesized that by the year 2030, human system operators will be “*cognitively challenged*” to keep pace with the demands of the most advanced weapon system designs. Some are calling for adoption of human cognitive enhancement coupled with flexible autonomy--forming human-machine teams--as a means to address challenges to United States technical superiority. While human cognitive enhancement may hold promise, the practice also raises questions and concerns. The potential for ethical implications is a matter United States policymakers must afford consideration. Some theoreticians go so far as to envision dynamic “*cognitive coupling*” of human system operators with flexible autonomous machines via brain computer interfaces. The resultant human-machine team is analogous with the Air Force vision for “Airman-machine teaming.” Airman-machine teaming raises questions regarding the imperative for maintaining human control over autonomous weapon systems. Control of lethal force demands special attention. Concerns are further heightened with the possibility of injecting human cognitive enhancement into the environment. This research paper explores ethical implications associated with adoption of human cognitive enhancement. As the Air Force considers adopting neurotechnologies and pursuing Airman-machine teaming, this paper argues continuous study and policy debate of the potential ethical implications are warranted.

## Introduction

As envisioned by the Joint Staff, and as expressed in the *Joint Operating Environment 2035* (JOE 2035), the United States (US) will face a most complex security atmosphere in the year 2035.<sup>1</sup> The future security environment will increasingly be characterized by disorder and chaos. Some, such as Antoine Bosquet, argue advances in science and technology promise to bring order to this “chaoplexic” warfare environment.<sup>2</sup> Irrespective of the potential for scientific and technological advances, Airmen are destined to face greater personal challenges to their individual human abilities: human cognitive performance is no exception.

The US Department of Defense (DoD) anticipates the joint warfighter, the human system operator, will be confronted with challenges to cognitive function beyond “*normal*” human capabilities. As envisioned, these future challenges to human cognitive capabilities will eclipse that which is generally considered “*natural*” human capacity. While future wars will continue to feature battles of physical feats, the multi-domain battlespace of the future will expand to include competition within a new “*mentalsphere*” dimension--a cognitive-machine space--seeking to establish cognitive supremacy of shared human-machine capabilities.

As Carl von Clausewitz notes in *On War*, “war is an act of force to compel our enemy to do our will.”<sup>3</sup> Clausewitz’s dictum highlights the application of physical force in war as a means to achieve the ultimate ends: shifting of an adversary’s mental attitude and psychological disposition. In Clausewitz’s view, the use of physical force in war is to compel one’s enemy--bending will and shifting mental intent. Nowhere is this mindset more prominent than within the sphere of cognitive thoughts and mental consciousness. Clausewitz’s thinking reflects an understanding of the importance of human cognitive capabilities in war.<sup>4</sup>

As warfare evolves unpredictably, with chaos and complexity increasingly defining the future multi-domain battlespace, discoveries associated with neuroscience and advancements in neurotechnology offer promise for maintaining US warfighting competitive advantage.

Neuroscience is focused on unlocking the mysteries of the human brain. According to the Society for Neuroscience, neuroscientists are focused on gaining a better understanding of the complexities associated with the human brain and for uncovering the secrets to unleash the full potential of humankind.<sup>5</sup> It is the view of neuroscientists that the human brain has more computing capacity than a modern supercomputer--capabilities valued by US warfighters.

As complicated as these challenges are, neuroscience is not confined simply to understanding the physical aspects of the human brain. Perhaps more daunting is the task of deciphering the billions of nerve cells, tissue fibers, chemical compositions and electrical impulses making up the human nervous system. Neuroscientists endeavor to understand the mental complexion of the human mind: our ability to “shape thoughts, beliefs, hopes, dreams, and imaginations.”<sup>6</sup> From a cognitive enhancement perspective, neuroscience is concerned as much with understanding the capabilities and functions of the brain, and if not more so, gaining an understanding of the inner workings of the mind.

Joined with neuroscience is neurotechnology--the implements of brain science. Recent advancements in neurotechnology hold promise for putting neuroscience into practice. Present-day advancements in neurotechnology herald to the mid-1960s when Grey Walter first demonstrated the application of a non-invasive encephalogram (EEG).<sup>7</sup> It was not long thereafter, in the early 1970s, that the Defense Advanced Research Agency (DARPA) got involved and first funded development of neurotechnology in the form of a brain-computer interface (BCI).<sup>8</sup> It is noted, DARPA’s interests in advancing neurotechnology in support of

warfighter applications has grown steadily ever since. DARPA recently issued Duke University's Center for Neuroengineering a \$26 million dollar contract as part of DARPA's Brain-Machine Interfaces Program to "develop new technologies for augmenting human performance by accessing the brain in real time and integrating the information into external devices."<sup>9</sup> The stated DARPA goal sounds very much like the AF vision for human cognitive enhancement and Airman-machine teaming. This level of support from DARPA demonstrates interest in developing brain-machine interfaces to gain advantage of directly interfacing human brains with machines, devices John Edwards refers to in *The Geeks of War* as "neurorobots."<sup>10</sup>

In 2015, no fewer than thirty thousand scientists and industry professionals gathered in Chicago for the annual Society of Neuroscience conference: brain function and cognitive enhancement were hot topics that year.<sup>11</sup> Indicative of this level of interest, ten neurotechnologies were showcased specifically relating to human cognitive enhancement. All ten would appear to have warfighter interests, and applicability:<sup>12</sup>

1. Big data-enhanced diagnostics and treatments
2. Brain-computer interfaces for device control
3. Real-time neuromonitoring (plus robotic aids)
4. Neurosensor-based vehicle operator systems
5. Cognitive training videogames
6. Brain-responsive computing systems
7. Virtual reality treatments (especially in conjunction with EEG and/or tDCS\*)<sup>13</sup>
8. "Mindful" wearables
9. Collaborative cognitive simulations
10. Electrical and magnetic brain stimulation



Given the level of DARPA's investment in neuroscience, one can argue the DoD clearly sees a need to pursue "leap ahead" neurotechnologies to maintain US technical superiority. As the AF moves closer towards adoption of neuroscience and neurotechnology to meet future complex challenges and counter growing adversarial threats, an assessment of potential ethical implications must be given greater consideration. In particular, as the AF looks to refine operational concepts under the auspices of Airman-machine teaming, notions of human cognitive enhancement in particular deserve scrutiny from an ethical perspective. With an awareness for the complexities envisioned in the JOE 2035 rapidly approaching, US policymakers could soon be confronted with calls to expedite adoption of neuroscience and neurotechnologies without having given potential ethical implications due consideration. With on-going research advancing at a rapid pace, now is the time to begin an examination of the potential ethical implications associated with adopting human cognitive enhancement.

The process of policy formulation need not await in anticipation of research findings and scientific facts to initiate the discussion and debate. As James Browning highlights in, *"Leading at the Strategic Level in an Uncertain World,"* senior leaders often will not have all the answers before they must start working to identify solutions for "wicked" problems.<sup>14</sup> Gaining a better appreciation of volatile, uncertain, complex and ambiguous (VUCA) problems is valuable in and of itself. Answers in these situations do not come easily, nor quickly.

The time has arrived for US policymakers to begin the discussion and initiate debate concerning potential ethical implications associated with human cognitive enhancement, and in the larger context, human-machine teams coupled with flexible autonomy.<sup>15</sup>

As envisioned, flexible autonomy represents a symbiotic relationship between human and machine (Airman-machine teaming is just one manifestation of this vision from an AF

perspective). Scientific discovery and associative policy development share a interdependent and reciprocal relationship. Scientific discovery must inform policy development; policy development must guide scientific discovery. This research paper highlights the need for an in-depth study examining potential ethical implications concerning human cognitive enhancement in association with Airman-machine teaming.

As the DoD and Joint Staff devise contingency plans to address potential future military conflicts, US policymakers must assess research discoveries and scientific possibilities to meet the future security needs of the joint warfighting force. Recent research discoveries concerning the human brain are pushing scientific possibilities for adopting human cognitive enhancement. What some today assert are future potentialities, tomorrow they may insist the same are absolute necessities. If policy debate is not initiated, adoption of human cognitive enhancement could become “*de facto ... fait accompli!*”

## **Thesis**

Airman-machine teaming is one personification of flexible autonomy. Through human cognitive enhancement, neuroscientists endeavor to augment “normal” human capabilities through neurotechnology to bring about improved human performance. This research paper argues potential ethical implications associated with human cognitive enhancement in association with flexible autonomy (Airman-machine teaming) are not being adequately addressed by US policymakers. As such, the AF is at risk for allowing science to proceed ... and precede ... policy regarding potential ethical implication of human cognitive enhancement.

Neuroscientific research on the human brain is proceeding at a rapid pace. Arguably, neuroscientific discovery and neurotechnological advancements are proceeding ahead of

discourse, debate and policy. While uncertainty must not hold science hostage, scientists share in responsibility for enlightening the discourse and fostering public policy debate.

The AF has articulated science and technology visions and future operating concepts, yet policy concerning potential ethical implications associated with flexible autonomy and human cognitive enhancement are lacking--ethics, principles and core values hang in the balance.

In furtherance of Airman-machine teaming, this paper calls for the AF to authorize a study effort with the goal of establishing official policy and setting operational guidelines addressing potential ethical implication associated with human cognitive enhancement and flexible autonomy. The study effort should seek to provide definitive answers to the following:

- 1) Are there ethical implications associated with human cognitive enhancement;
- 2) Does human cognitive enhance jeopardize the concept of human control?

In support of these arguments, this research paper examines DoD and AF policy and pronouncements regarding autonomy, and science and technology in general. In particular, areas concerning ethics relating to human cognitive enhancement were a focus of research. While considerable investment is being made in neuroscience and neurotechnology, as noted by the DARPA example cited, there is little evidence ethics is receiving seriously considerations. As this research paper notes, neither the 2012 nor the 2016 Defense Science Board reports on autonomy address ethics. Further, discussion is presented regarding questions and concerns associated with jeopardizing independent human control, accountability and responsibility as a result of implementation of flexible autonomy in association with human cognitive enhancement. A discussion of possible consequences to the Law of Armed Conflict and Just War theory is presented for contemplation. In summary, this research shows policy debate regarding potential ethical implications concerning flexible autonomy and human cognitive enhancement is lacking.

## A Glimpse Into The Future

### *“Neuroweapons?”*

The *US Air Force Future Operating Concept* (AFFOC) establishes a vision for how Airmen and Airpower will meet the security challenges depicted in the JOE 2035.<sup>16</sup> Scenes in the AFFOC depict future weapon systems (machines) and human system operators (Airmen) teamed as interdependent partners via intelligent technologies fighting across multi-domain environments. As an inspiring and aspirational document, the AFFOC is afforded literary license for omitting some details for how human system operators will achieve the seemingly science fiction feats illustrated in the vignettes.<sup>17</sup> Not to dismiss these futuristic ideas and concepts, but as the AF plans for organizing, training and equipping the “*The World’s Greatest Air Force*,” reality eventually enters the picture through science and technology investments and funded acquisition programs.<sup>18 19</sup> With interest in human cognitive enhancement and Airman-machine teaming heightened, now is an opportune time to engage in theoretical inquiry regarding the potential of ethical implications. Philosophical questions are best considered in advance of programmatic decisions allowing sufficient time for well-reasoned discussion and balanced debate before reality presents the problem in demanding terms hastening well-reasoned considerations.

It is hypothesized that by the year 2030, human cognitive capabilities will be challenged to keep pace with the “enormous data volumes, processing capacities, and decision speeds” associated with future weapon systems.<sup>20</sup> We already see evidence of this future reality. Past studies exploring mental workload and task demands levied on human system operators of command and control (C2) systems support this hypothesis.<sup>21</sup> The recent 2008 National Academy of Sciences publication on emerging technologies highlighted possible military

applications of neuroscience for the purposes of enhancing human cognitive functionality.<sup>22</sup> Specifically mentioned in the 2008 report are recommendations for the US Army to increase funding for scientific research associated with transcranial magnetic stimulation (TMS) and examine modern pharmaceutical technologies (e.g. modafinil, methylphenidate, etc.). It is the view of the National Academy of Sciences these modern neurotechnologies may hold promise with military utility (e.g. suppressing effects of sleep deprivation and increasing alertness).<sup>23</sup> In a separate, but somewhat related work, Rachel Wurzman and James Giordano note the potential for development of defense-oriented neurotechnologies to create “*neuroweapons*.”<sup>24</sup>

With this view of the future in mind, it is easy for one to visualize seeds of requirements germinating as expressions of future operational imperatives--ruminations taking shape in the form of formal joint warfighting operational requirements. The vision for Airman-machine teaming and flexible autonomy resonates with this view.

The US is pursuing advancements in unmanned systems, robotics, and autonomy as ways and means to meet future security needs. The AF science and technology strategy does not envision supplanting humans completely, yet the AF strategy envisions capitalizing on and leveraging the unique strengths and capabilities of human system operators seamlessly matched with the distinctive benefits of flexible autonomous machines.<sup>25</sup>

## **A Human Touch**

### **Maintaining Balance ... Perspective**

The uniquely human capacity for independent thought, judgement and reasoning ... must be retained. However, at the same time, it is this very human capability for cognitive function that is potentially the limiting factor in a future complex world. The challenge as seen is how best to effect Airman-machine teaming without violating human autonomy or undermining

human control. Nowhere is this concern more important than in policy discussions surrounding the use of lethal force.

When it comes to Airman-machine teaming and implementation of autonomy, DoD policy regarding the use of lethal force is clearly stated. Deputy Secretary of Defense Robert Work states the US position unequivocally, “we believe strongly that humans should be the only ones to *decide* when to use lethal force.” Secretary Work’s comments are not referring to human physical control, but more importantly that of human mental attitude and judgement--the uniquely human ability to reason and decide. In his statement, Secretary Work foresaw a time in the not too distant future when the US will be confronted with the question of human cognitive enhancement, “Now our adversaries quite frankly are pursuing enhanced human operations and it scares the crap out of us, really. We’re going to have to have a big, big decision on whether we’re comfortable going that way.”<sup>26</sup> For the foreseeable future, US policy will most likely continue to require direct human operator involvement in the use of lethal force, however, a time is nearing when the question of human cognitive enhancement must be addressed. As the DoD assesses the ramifications of human-machine teaming and interactive cognitive partnering is considered along with human cognitive enhancement, questions and understanding concerning “control” of lethal force will grow in importance. These questions will demand as much a scientific and technological debate as they will a philosophical discussion concerning moral imperatives and ethical implications. The ethical implications of such questions have far reaching implications relating to US policy, International law, and theory guiding Just War.

As the DoD plans, programs, and prepares the military force of the future ... to meet the security challenges of the future ... the US must not wait to address questions concerning potential ethical implications surrounding human cognitive enhancement.

## A New War Order

### The “Big, Big” Question Before Us

In November 2014, US Secretary of Defense Chuck Hagel announced creation of the Defense Innovation Initiative (“Third Offset”) strategy to advance technologies including robotics, artificial intelligence, autonomous systems, and big data.<sup>27</sup> Answering this call for advancing technologies to meet future demands, the US Air Force year 2030 strategy, *America’s Air Force: A Call to the Future*, recognizes unmanned and autonomous weapon systems as potential game-changing technologies.<sup>28</sup> The Air Force envisions the application of flexible autonomy to “form a central tenet for future human-autonomy interaction.”<sup>29</sup> Flexible autonomy will come to represent the state of interaction between unmanned systems and human system operators: the two working together--interdependently--in a symbiotic relationship.<sup>30</sup>

Providing some definition and context to the concept of human-machine teaming, Deputy Defense Secretary Work adds, “Human-machine collaboration is allowing a machine to help humans make better decisions faster. That is a big, big difference. There is an artificial intelligence (AI) bias right now generally in the community [i.e. using unmanned systems to replace humans, rather than *augment* them]. But...automated systems use algorithms based on old data, [and] we’re up against a thinking adversary that is changing strategies all the time.” In Secretary Work’s remarks, one finds concern for the adversarial threat developing as a prime motivating factor for the US to advance concepts of human-machine teaming, and the capabilities envisioned through such partnership.

“Thinking machines’, robotics embedded with artificial intelligence and augmenting, offsetting human ‘handling cognitive task,” is how Erik Brynjolfsson and Andrew McAfee describe the future in *The Second Machine Age*.<sup>31</sup> The idea is not about machines replacing humans; it is

about machines and humans working in tandem, cognitively coupled as partners. The essence of this vision is analogous with the AF concept of Airman-machine teaming. As military futurist Paul Scharre imagines the potential for human-machine teaming, “It’s actually not an either-or. Like the mythical centaur, we can harness inhuman speed and power *to human judgement*. We can combine machine precision and reliability, human robustness and flexibility.”<sup>32</sup> As Scharre describes the potential of human-machine teaming, “... it’s not just about manned and unmanned vehicles moving together, it’s also about computers and humans helping each other to *think*. That’s “cognitive teaming.”<sup>33</sup>

Given descriptions provided by Work and Scharre, one can begin to see how advances in human-machine teaming can make it difficult to separate the thoughts of the human from actions of the machine. Will there be any separation between human cognitive thought and machine physical action. Likewise, one might ask how this close association, an interdependent, symbiotic relationship between living human beings and autonomous machines may affect human thought and decision making.

### **Is Cognitive Enhancement ... Already A Foregone Conclusion?**

Establishing conditions necessary for adoption of unmanned and autonomous systems, in support of Airman-machine teaming, the *Air Force Technology Horizons* matter-of-factly states, “Humans and machines will need to become far more closely coupled through improved human-machine interfaces and by *direct augmentation of human performance*.”<sup>34</sup> The *Air Force Future Operating Concept* (AFFOC) calls for the development of human-machine systems in support of the year 2035 force of the future operations.<sup>35 36</sup> As such, the AFFOC notes, “As a force development concept, the *AF Future Operating Concept* is subject to testing, experimentation, evaluation and assessment to validate its ideas and/or suggest better alternatives.”<sup>37</sup> Cautioned in



the AF strategy, *America's Air Force: A Call to the Future*, is a warning “not to allow technology to outpace legal, moral, and doctrinal considerations.”<sup>38</sup> In light of Secretary Works’ comments noted earlier, and as expressed in the *Air Force Technology Horizons*, it is prudent for US policymakers and the DoD to heed a cautionary note regarding ethical implications associated with human cognitive enhancement.

*Technology Horizons* acknowledges concerns associated with some forms of neuroscientific techniques and human cognitive enhancement, “while such methods may appear inherently distasteful, potential adversaries may be entirely willing to make use of them.”<sup>39</sup> Acknowledging concerns exist, it is important to evaluate and assess the ethical implications and policy considerations associated with adoption of neurotechnology relating to human cognitive enhancement and not allow a drive to match adversaries push the US to violate ethical principles.

### **The Head of the Matter**

*Intelligent machines seamlessly integrated with humans – maximizing mission performance in complex and contested environments*<sup>40</sup>

Greg L. Zacharias, PhD, SES, Chief Scientist of the Air Force

### **Controlling Thought: Human or Machine**

As Department of Defense Directive 3000.09 states, “Autonomy in Weapon Systems,” it is DoD policy for autonomous (semi-autonomous or flexible autonomous) weapon systems to “... be designed to allow commanders and operators to *exercise appropriate levels of human judgement* over the use of force.”<sup>41</sup> As the title of DoDD 3000.09 implicates, the primary subject of the directive surrounds the use of autonomy in weapon systems. Thus, the directive is principally concerned with autonomy, the machine aspect of the weapon system, and not the human operator element of control. While the directive stipulates human operator involvement, or “control by,” the directive is silent regarding the cognitive component of *human judgement*.

From a cognitive perspective, it would appear there is ambiguity surrounding what constitutes human control. This uncertainty adds to the unease regarding adoption of autonomy with Airman-machine teaming, coupled with the potential for human cognitive enhancement. In light of the previous discussion regarding the real and foreseeable potential for human cognitive enhancement, the AF must assess if there are resultant ethical implications by effecting change to a human system operator's cognitive state. Does human cognitive enhancement sufficiently alter or shift mental state thus jeopardizing human control?

Calls for adoption of neurotechnology to advance human cognitive capabilities demand prudent consideration. Recognizing human judgement is correlated with reasoning and decision making, and is a joined facet of cognition, arguably, human cognitive enhancement could have some impact on an individual's ability to reason clearly. The concern is: can human cognitive enhancement impair judgement sufficiently and negatively to violate the concept of self and human control. As much remains unknown regarding the deeper functions of the human brain, scientists must resist the allure of "technological imperative" to use technology simply because it is available.<sup>42</sup> Even allowing for greater understanding of the structures of the brain, as a result of advancements in brain imaging and neuro sensory technologies, there is still much speculation regarding mental cognition and precise brain function. This is especially true concerning the phenomenon of thought and consciousness.<sup>43</sup>

In their examination of autonomous weapons systems, Michael Horowitz and Paul Scharre produced a report, *Meaningful Human Control in Weapons Systems: A Primer*, addressing the question for what substantiates "meaningful" human control. In their report, Horowitz and Scharre propose two conditions relating to the human operator:

- 1.) Humans make informed and conscious decision.

2.) Information available is sufficient to ensure action lawful.

Considering the question of impact of cognitive enhancement on the reasoning ability of human subjects, the stipulation for informed and conscious decision deserves greater examination.

Much mystery remains concerning dualism and the connections between brain and mind. As David Chalmers equates the situation in the *Journal of Consciousness Studies*, demonstrating causality between brain function and conscious thoughts remains one of the “hard problems” of neuroscience.<sup>44</sup> Recognizing that uncertainty and risk are ever-present facets of scientific discovery, scientist must approach application of neurotechnology with trepidation.

Over the course of the past few decades there has been much research into the depths of the human brain. Medical discoveries have revealed many mysteries surrounding the features and structures of the human brain. As an anatomical organ, the human brain is fairly well documented. However, when it comes to the human mind, less is understood. The phenomenon of consciousness in particular remains much a mystery. As James Giordano argues, this set of circumstances should not dissuade neuroscience research and development.<sup>45</sup> Rather, Giordano favors pursuing research since the outcomes provide a foundation of knowledge from which to develop understanding for how to handle unexpected outcomes.<sup>46</sup> As the AF considers opportunities for advancing human cognitive enhancement, in association with Airman-machine teaming, the sentiments of Giordano ring true: research and discovery must inform policy formulation ... policy must guide science and technology efforts.

### **The Evolution of “Autohumachine”**

The dynamism of an “adversarial-response dilemma,” the feeling of an imperative and compunction to respond to threats in like mind can be strong motivating forces pushing US

decision makers to pursue new technology such as human cognitive enhancement. Robotics, autonomy, artificial intelligence, and unmanned weapon systems are just some of the advanced technologies often highlighted as key to the US maintaining technological superiority over our adversaries.<sup>47</sup> While the names of these futuristic technologies can convey a perception of human-less or operator-less weapons systems, as the *DoD Unmanned Systems Integrated Roadmap* attests, nothing could be farther from reality.<sup>48</sup> Even the most advanced application of autonomy envisions some form of interaction between human and machine.

As Dr. Vladimir Djapic highlights in the monograph, *Optimizing the Human Element in the Age of Autonomy*, achieving optimization of autonomous weapon systems is predicated on maximizing the inherent strengths of human operators and exploiting advanced technical capabilities of autonomous machines.<sup>49</sup> The 2012 DoD Defense Science Board task force report on *The Role of Autonomy in DoD Systems* supports this assessment.<sup>50</sup> Interestingly, neither the 2012 DoD Defense Science Board report on autonomy, nor the more recent 2016 DSB report, addresses the question of human cognitive enhancement.<sup>51</sup> Further, these reports are silent on the subject of ethical considerations regarding human-machine teaming. A lack of discussion by the DSB concerning ethics is further evidence demonstrating the need for study and debate.

## **Moving Beyond Research to Policy Considerations**

### **Dynamic Human-Machines ... Brain-Based Designs**

As Steve Murray and Matthew Yanagi posit in *Transitioning Brain Research: From Bench to Battlefield*, future autonomous system designs will likely be based on elements of human neuroscience research including human-machine interactions. Future human-autonomous systems will likely include real-time human operator physiological state sensing, dynamic task allocation, and bi-directional feedback.<sup>52</sup> Murray and Yanahi highlight some of the most

promising neuroscience-related capabilities associated with man-machine teaming having potential for national security application:

- Human cognitive performance: gaining better understanding of processes involved with memory, emotion, and reasoning which can lead to improved task design and decision support systems.
- Training efficiency: enabling rapid mastery of knowledge with improved retention.
- System engineering: include technologies supporting shared-initiative problem solving between humans and machines.

In order for scientists to advance neuroscience research discoveries to support human-machine teaming, engineers must explore creating new architectures supporting cognitive task allocation and dynamic balancing between human system operators and intelligent autonomous machines. As Murray and Yanagi highlight in their writing, while scientific discoveries and technological advances promise potential, they also present a hosts of unique challenges that must be addressed in order to successfully transition neuroscience to future weapon system designs.<sup>53</sup> In order to develop systems supporting shared information processing and dynamic association between human (brain-based) and machine (flexible autonomy), the following transition challenges must be addressed:

- Minimize disruption: scientific and research community should adopt a gradual “stepwise” approach to introduce and adopt brain-based technologies.
- Define agency and responsibility: initiate multi-disciplinary dialogue to establish and define rules and norms guiding implications of brain-based system designs.

- Design for transparency: as brain-based designs will reflect operator cognitive state, standards must be developed to protect privacy and provide system surety.

As highlighted in the National Research Council report, *Emerging Cognitive Neuroscience and Related Technologies*, potential advancements in human-machine and brain-based systems holds promise for improving future mission performance.<sup>54</sup> However, implementation of brain-based human-machine designs demands consideration early in the design process for potential ethical implications. Murray and Yanagi suggests “neuro research” scientists should look to recent examples from human factors engineering (HFE) and human systems integration (HSI) when assessing the potential for integration of human-machine systems. Two pertinent suggestions the AF should consider in relationship to Airman-machine teaming includes:

- Engage user community early to identify applications for technologies
- Adopt iterative approach to incremental testing in operational environment

### **Cognitive Enhancement ... Just War Impact**

As the DoD and AF consider human-machine teaming, US policymakers must assess how human cognitive enhancement may negatively impact Just War theory. Principles governing human conduct in war are rooted in *Just War* theory as reflected in the *Law of Armed Conflict*.<sup>55</sup> Principles of Just War are largely based on two elements: *Jus ad bellum* (declaration of war) and *Jus in bello* (conduct of war). *Jus in bello* captures the essence of one’s individual responsibility in war, to include responsibility for exercising sound judgement over the application of lethal force.

With respects to human cognitive enhancement, it is *jus in bello* which is pertinent to the discussion regarding potential ethical implications surrounding human cognitive enhancement.

As human cognitive enhancement has some potential to alter one's perceptions (of reality), thereby affecting associative judgements, could the resultant impairment potentially jeopardize human autonomy and bring into question assignment of responsibility?

Individual responsibility according to *jus in bello* is governed by three explicit conditions: discrimination, proportionality, and necessity.<sup>56</sup> To maintain the integrity of *Jus in bello*, and individual responsibility, all three conditions must exist without impairment or degradation:

- Discrimination: individual must be able to distinguish legitimate actions
- Proportionality: actions taken and response must be balanced
- Necessity: actions must be just in cause

Analogous to the three conditions identified above relating to *jus in bello*, Christopher Cowley argues in *Moral Responsibility* of four preconditions necessary for assignment of individual responsibility: capacity, understanding, control, and accurate perception.<sup>57</sup>

- Capacity: agent must possess mental capacity to discern actions and events
- Understanding: agent must comprehend situation connected with one's role
- Control: agent must maintain positive awareness of situation, be cognizant
- Accurate perceptions: agent must possess an unaltered consciousness and state of mind.

Accepting that human cognitive enhancement does somewhat alter one's perceptions of reality, thereby potentially affecting judgement of relevant facts, arguably there is some risk human cognitive enhancement may negatively impact the Just War concept of *Jus in bello*. Should human cognitive enhancement jeopardize individual responsibility, corresponding accountability would suffer.

## **Human-Machine Interaction ... “Locus of Control” Concern**

Human-machine interaction further raises ethical concerns regarding responsibility and accountability. Of particular concern is the fundamental imperative regarding “human control” over lethal force. The pertinent question to assess is: does human-machine teaming (the aspect of interdependent interaction created by human-and-machine teaming) sufficiently injure human autonomy to void assignment of responsibility. Should Airman-machine teaming and flexible autonomous weapon system designs advance to where it become difficult to discern locus of control (is control of action due to human thoughts or external machine response), a concern for shared responsibility is raised. This concern is compounded should the human-machine teaming scheme include human cognitive enhancement clouding responsibility assignment. Recognizing machines cannot be held liable, the concern is for the unwitting creation of a responsibility gap with no party capable of being held accountable for actions.

## **LAWS ... Lethal Autonomous Weapon Systems**

There is much concern regarding the use of autonomous weapons systems in war, especially in association with the application of lethal force.<sup>58</sup> The terms “killer drone” and “killer robot” are occasionally used to refer to what is more precisely and correctly characterized as a Remotely Piloted Aircraft weapon system. Disregarded in these depictions is an acknowledgement of a human operator providing oversight of the weapon system, and human initiation and control regarding decisions associated with the employment of lethal force. Some have argued a moratorium or ban be imposed on further development and use of unmanned weapon systems until a full review of ethical issues is conclusively settled.<sup>59</sup>

Adding to the above concerns regarding unmanned weapon systems are questions relating to adoption of autonomy and artificial intelligence in armed weapon systems. The



subject of Lethal Autonomous Weapons (LAWS) was recently raised at the United Nations (UN) Convention on Certain Conventional Weapons in May 2014.<sup>60</sup> One of the concerns expressed by the UN surrounds the question: what constitutes “meaningful human control” of an autonomous weapon systems.<sup>61</sup> As brought forth earlier in discussion concerning DoDD 3000.09, the DoD policy on human operator control over autonomous weapon systems in respects to application of lethal force is well established.<sup>62</sup> In DoDD 3000.09 parlance, commanders and operators have a duty to exercise “appropriate human judgement.” By extension of customary international law, commanders can be held liable for improper or illegal actions committed by operators if the action is the direct result of commander issued direction.<sup>63</sup> At this juncture it is relevant to review the philosophical underpinnings that govern conduct of war and guide discussions regarding characterization of human control as DoDD 3000.09 states, to exercise “appropriate human judgement.”

### **Explain the Meaning -- Human Control**

The term “appropriate” human control as applied in DoDD 3000.09 lacks definition.<sup>64</sup> As such, there is vagueness surrounding what constitutes adequate human control of autonomous weapon systems. In light of the previous discussion surrounding potential ethical concerns regarding human cognitive enhancement, this uncertainty fuels a debate concerning the use of autonomy, and in particular in conjunction with lethal weapon systems. For some, the UN effort to qualify human control is in effect an attempt to ban the use of unmanned and/or autonomous weapon systems. Understanding some may seek to use the question of “appropriate” or “meaningful” human control to restrict the use of autonomy or guide policy discussions surrounding adoption of human cognitive enhancement, the DoD and AF would be well served by exploring the issue of “human control” in light of concepts for Airman-machine teaming.

## **Recommendation**

As the AF considers pursuing flexible autonomy (Airman-machine teaming) and adopting human cognitive enhancement, it is recommended a formal study effort be commissioned to review questions and address concerns relating to potential ethical implications.

As outlined in this research paper, the study should be informed by scientific researchers representing all relevant sciences, and balanced with full participation and views heard from a wide variety of concerned stakeholders. The results of such an effort could serve as guiding future research and supporting science and technology investment decisions. The ensuing discourse would have the added benefit of setting “officially” AF policy regarding these matters.

The study effort should seek to provide definitive answers to the following:

- 1) Are there ethical implications associated with human cognitive enhancement;
- 2) Does human cognitive enhance jeopardize the concept of human control?

## **Conclusion**

The US warfighter will face a highly complex security environment in the future. The stakes will be high. A multi-domain environment will only add to the “cognitive challenge” facing weapon system operators. An Airman’s future wingman could very well be a machine.

Science and technology holds promise for providing capabilities to cope with the mental demands ... but our adversaries will not rest. Autonomy, human-machine teams, and cognitive enhancement all offer potential. Some philosophers argue there is a moral obligation to pursue human performance enhancement, yet the question of ethics remains ... largely unanswered.<sup>65</sup>

As science and technology are assessed, scientists owe more than a technology roadmap. The onus for charting policy is a shared responsibility, by researcher and operator equally. For

policy to be sound, debate must be fully informed. Stakeholders must guard against unconscious bias and rationalization. The stakes are just too high.

Recognizing much uncertainty exists in the realm of neuroscience and brain-mind function, scientists must continue to update beliefs with relevant scientific knowledge. As application of neurotechnology in weapons system designs could potentially lead to significant consequences, the situation requires continual examination, discussion, debate and dialectic discourse. Policy must represent varied interests, disciplines and views--from all stakeholders.

As the DoD and AF make designs on future warfighting capabilities, pursuit of combat advantage must remain balanced with our core values and not come at the expense of ethics.

For the US warfighter ... the stakes are high!



## Notes

1. The Joint Staff, *Joint Operating Environment (JOE) 2035 (JOE 2035) – The Joint Force in a Contested and Disordered World*, 14 July 2016.
2. Antoine Bosquet, *The Scientific Way of Warfare: Order and Chaos on the Battlefields of Modernity* (New York: Columbia University Press, 2009)
3. Carl von Clausewitz, *On War*, trans. Peter Paret and Michael Howard, 75.
4. Ibid., 78.
5. Society for Neuroscience, <https://www.sfn.org/about/about-neuroscience>.
6. Robbin A. Miranda, et al, *Journal of Neuroscience Methods*, DARPA-funded Efforts in the Development of Novel Brain-Computer Interface Technologies, Volume 244 (2014), 52-67.  
Note: Electroencephalography (EEG) is an electrophysiological monitoring method to record electrical activity of the brain. It is typically noninvasive, with the electrodes placed along the scalp, although invasive electrodes are sometimes used in specific applications. EEG measures voltage fluctuations resulting from ionic current within the neurons of the brain.
7. Robbin A. Miranda, et al, *Journal of Neuroscience Methods*, DARPA-funded Efforts in the Development of Novel Brain-Computer Interface Technologies, Volume 244 (2014), 52-67.  
Note: Electroencephalography (EEG) is an electrophysiological monitoring method to record electrical activity of the brain. It is typically noninvasive, with the electrodes placed along the scalp, although invasive electrodes are sometimes used in specific applications. EEG measures voltage fluctuations resulting from ionic current within the neurons of the brain.
8. Ibid.
9. John Edwards, *The Geeks of War - The Secretive Labs and Brilliant Minds Behind Tomorrow's Warfare Technologies*, (New York: AMACOM, 2005), 123.
10. Ibid, 123.
11. Alvaro Fernandez, Sharp Brains: Tracking Health and Wellness Applications of Brain Science, “10 Neurotechnologies About to Transform Brain Enhancement and Brain Health,” 10 November 2015, <http://sharpbrains.com/blog/2015/11/10/10-neurotechnologies-about-to-transform-brain-enhancement-and-brain-health/>
12. Ibid.
13. \*Transcranial Direct Current Stimulation (tDCS): is a non-invasive, painless brain stimulation treatment that uses direct electrical currents to stimulate specific parts of the brain. A constant, low intensity current is passed through two electrodes placed over the head which modulates neuronal activity. There are two types of stimulation with tDCS: anodal and cathodal stimulation. Anodal stimulation acts to excite neuronal activity while cathodal stimulation inhibits or reduces neuronal activity. Source: John Hopkins Medical Hospital, Brain Stimulation Project: [http://www.hopkinsmedicine.org/psychiatry/specialty\\_areas/brain\\_stimulation/tDCS.html](http://www.hopkinsmedicine.org/psychiatry/specialty_areas/brain_stimulation/tDCS.html)
14. James W. Browning, *Leading at the Strategic Level in an Uncertain World*, (Washington, DC: NDU Press, 2013).

15. Mica Endsley, “*Autonomous Horizons – System Autonomy in the Air Force – A Path to the Future, Volume I: Human-Autonomy Teaming*,” Technical Report, United States Air Force, Office of the Chief Scientist (AF/ST TR15-01), June 2015.
16. *United States Air Force Future Operating Concept (AFFOC) – A View of the Air Force 2035*, September 2015.
17. Lt Col William M. Curlin, Air War College, Academic Year 2017, Future Conflict and Air Warfare (FCA) Course (6501), course student paper, “Future Operating Concept: Joint Warfare/Combined Battlespace Command & Control (JWCBC2),” 26 Jan 17.
18. Mark A. Welsh III, “*A Vision for the United States Air Force. The World's Greatest Air Force - Powered by Airmen, Fueled by Innovation*,” (Pentagon, Washington, D.C.: United States Air Force, 2014).
19. Mark A. Welsh III, “*Global Vigilance, Global Reach, Global Power for America. The World's Greatest Air Force - Powered by Airmen, Fueled by Innovation*,” (Pentagon, Washington, D.C.: United States Air Force, 2014).
20. W. Dahm, “*Report on Technology Horizons (Technology Horizons): A vision for Air Force science & technology during 2010-2030*,” Technical Report, United States Air Force, 2010, xxi.
21. Lt Col John T. Ackerman, PhD, USAF, Retired and Col Kathleen Mahoney-Norris, PhD, USAFR, Retired, ed., *Future Trends and US National Security* (Air University Press: Maxwell AFB AL), January 2015; Lt Col Lourdes M. Duvall, *Accounting for Human Information Processing*, Chapter 4, 71-95.
22. Jean-Lou Chameau et al., *Emerging and Readily Available Technologies and National Security – A Framework for Addressing Ethical, Legal, and Societal Issues* (Washington DC: The National Academies Press, 2014), 68., as cited, *Emerging Cognitive Neuroscience and Related Technologies*, Committee on Military and Intelligence Methodology for Emergent Neurophysiological and Cognitive /Neural Science Research I the Next Two Decades (National Research Council of the National Academy of Sciences 2008).
23. Ibid., 69-71.
24. James J. Giordano ed., *Neurotechnology in National Security and Defense: Practical Considerations, Neuroethical Concerns* (Boca Raton, FL: CRC Press, 2015); Rachel Wurzman and James Giordano, “*NEURINT*” and *Neuroweapons: Neurotechnologies in National Intelligence and Defense*, 2011, 79-113.
25. Ibid., W. Dahm, (2010). 10a. M. Endsley, (2015). 10b. AFRL *S&T Strategy* (2013).
26. Sydney J. Freeberg Jr., Defense News Online, “Will US Pursue ‘Enhanced Human Ops?’ DepSecDef Wonders”, <http://breakingdefense.com/2015/12/will-us-pursue-enhanced-human-ops-depsecdef-wonders>, 9 Nov 15.
27. Chuck Hagel, Secretary of Defense Speech, Reagan National Defense Forum Keynote, as Delivered by Secretary of Defense Chuck Hagel, Ronald Reagan Presidential Library, Simi Valley, CA, Nov. 15, 2014, <http://www.defense.gov/News/Speeches/Speech-View/Article/606635>.

28. United States Air Force Strategy, *America's Air Force: A Call to the Future*, July 2014, 18-19.

29. M. Endsley, "Autonomous Horizons – System Autonomy in the Air Force – A Path to the Future, Volume I: Human-Autonomy Teaming," Technical Report, United States Air Force, Office of the Chief Scientist (AF/ST TR15-01), June 2015, 9.

30. U.S. Air Force Research Laboratory, *Autonomy Science and Technology Strategy*, December 2013.

31. Erik Brynjolfsson and Andrew McAfee, *The Second Machine Age: work progress, and prosperity in a time of brilliant technologies* (London: Norton, 2014), 91-93.

32. Sydney J. Freeberg Jr., Defense News Online, "Centaur Army: Bob Work, Robotics, & The Third Offset Strategy", <http://breakingdefense.com/2015/11/centaur-army-bob-work-robotics-the-third-offset-strategy>, 9 Nov 15

33. Ibid.

34. Ibid., *Technology Horizons*, xxi

35. U.S. Air Force Future Operating Concept – A View of the Air Force 2035, September 2015, 9 & 44.

36. Headquarters United States Air Force Strategic Master Plan, May 2015, 42-47.

37. Ibid., *AF Future Operating Concept*, 4.

38. Ibid., *America's Air Force: A Call to the Future*, 19.

39. Ibid., *Technology Horizons*, xxi

40. Greg L. Zacharias, PhD, SES, Chief Scientist of the Air Force, Air Force Research Laboratory (AFRL) Autonomy Science and Technology (S&T) vision, as reflected in written testimony submitted for presentation to the House Armed Services Committee, Subcommittee on Emerging Threats and Capabilities, U.S. House of Representatives, SUBJECT: Advancing the Science and Acceptance of Autonomy for Future Defense Systems, 19 November 2015, 5.

41. Department of Defense Directive 3000.09, "Autonomy in Weapon Systems," November 12, 2012

42. Hans Lenk, *Technokratie als Ideologie: Sozialphilosophische Beitrage zu Einem Politischen Dilemman*, (Stuttgart, Germany: Kohlhammer, 1973).

43. David Chalmers, "Facing Up to the Problem of Consciousness," *Journal of Consciousness Studies* 2, no 3. 1995, 200-219.

44. Ibid.

45. James J. Giordano ed, *Neurotechnology: Premises, Potential and Problems*, (Boca Raton, FL: CRC Press, 2012), 99.

46. Ibid.

47. Chuck Hagel, US Secretary of Defense, Reagan National Defense Forum Keynote, remarks as delivered by Secretary of Defense Chuck Hagel, Ronald Reagan Presidential Library, Simi Valley CA, 15 November 2014.



48. Department of Defense Unmanned Systems Integrated Roadmap - FY2013-2038, Reference Number: 14-S-0553.

49. Dr. Vladimir Djapic et al, *Optimizing the Human Element in the Age of Autonomy*, presented on 5 May 15 at AUVSI Unmanned Systems Conference 2015, Atlanta, GA, <http://www.auvsishow.org/auvsi2015/public/SessionDetails.aspx?FromPage=Sessions.aspx&SessionID=955&SessionDateID=23>, and accessed at: [http://www.public.navy.mil/spawar/Pacific/Robotics/Documents/Publications/2015/AUVSI\\_Optimizing\\_HE.pdf](http://www.public.navy.mil/spawar/Pacific/Robotics/Documents/Publications/2015/AUVSI_Optimizing_HE.pdf)

50. Office of the Secretary of Defense, Defense Science Board, “SUBJECT: Final Report of the Defense Science Board (DSB) Task Force on the Role of Autonomy in Department of Defense (DoD) Systems”, 19 July 2012.

51. Ibid. 33a. Office of the Secretary of Defense, Defense Science Board, “SUBJECT: Final Report of the Defense Science Board (DSB) Summer Study on Autonomy” 10 June 2016.

52. James J. Giordano ed., *Neurotechnology in National Security and Defense: Practical Considerations, Neuroethical Concerns* (Boca Raton, FL: CRC Press, 2015); Steve Murray and Matthew A. Yanagi, *Transitioning Brain Research: From Bench to Battlefield*, 2011, 11-22.

53. Ibid.

54. National Research Council, *Emerging Cognitive Neuroscience and Related Technologies*, (Washington, DC: National Academies Press, 2009).

55. US Department of Defense, *The Armed Forces Officer*, (Washington DC: National Defense University, 2007), 11-20.

56. Ibid.

57. Christopher Cowley, *Moral Responsibility*, (New York: Routledge, 2014), 26-28.

58. Nehal Bhuta et al, *Autonomous Weapons Systems: Law, Ethics, Policy* (Cambridge: Cambridge Univ. Press, 2016)

59. Matthew Evangelista and Henry Shue ed., *The American Way of Bombing: Changing Ethical and Legal Norms, from Flying Fortresses to Drones*, (Ithaca NY: Cornell Univ. Press: 2014); Mary Elenn O’Connell, “*Banning Autonomous Killing: The Legal and Ethical Requirement That Humans Make Near-Time Lethal Decision*”, Chapter 12, 224-299.

60. Michael Møller, Acting Director-General of the United Nations Office at Geneva, remarks at the opening session of the Convention on Certain Conventional Weapons (CCW) Meeting of Experts on Lethal Autonomous Weapons Systems, Palais des Nations in Geneva, 13 May 14, access at: <http://www.un.org/apps/news/story.asp?NewsID=47794#.WI-cgaq7qis>

61. Michael Horowitz and Paul Scharre, *Meaningful Human Control in Weapons Systems: A Primer*, Center for a New American Security, March 2015

62. Department of Defense Directive 3000.09, “Autonomy in Weapon Systems,” November 12, 2012

63. James J. Giordano ed., *Neurotechnology in National Security and Defense: Practical Considerations, Neuroethical Concerns* (Boca Raton, FL: CRC Press, 2015); James P. Farwell,

*Issues of Law Raised by Developments and Use of Neuroscience and Neurotechnology in National Security and Defense*, 144.

64. Ibid., DoDD 3000.09.

65. Maartje Schermer et al., *The Future of Psychopharmacological Enhancements: Expectations and Policies* (Neuroethics, 2009), 80.





## Bibliography

- Bhuta, Nehal, and Robin GeiB, Hin-Yan Liu, and Claus KreB Susanne Beck. 2016. *Autonomous Weapons Systems: Law, Ethics, Policy*. Cambridge, UK: Cambridge University Press.
- Bobtsov, Alexey A., and Alexandr S. Borgul. 2013. "Human-Machine Interface for Mechatronic Devices Control." 7th International Federation of Automatic Control - Conference on Manufacturing Modelling, Management, and Control (19-21 June 2013). Saint Petersburg, Russia: IFAC. 614-618.
- Bolt, Ineke, and and Maartje Schermer. 2009. "Psychopharmaceutical Enhancers: Enhancing Identity?" *Neuroethics* (Springer) (2): 103-111. [springerlink.com](http://springerlink.com).
- Browning, James W. 2013. *Leading at the Strategic Level in an Uncertain World*. Washington, DC: NDU Press.
- Carter, Ashton B., Deputy Secretary of Defense. 21 November 2012. *Department of Defense Directive 3000.09 - Autonomy in Weapon Systems*. DoDD 3000.09, Pentagon, Washington, D.C.: United States Department of Defense, Undersecretary for Policy.
- Chameau, Jean-Lou, and and Herbert S. Lin, Editors William F. Ballhaus. 2014. *Emerging and Readily Available Technologies and National Security - A Framework for Addressing Ethical, Legal, and Societal Issues*. Center for Engineering, Ethics, and Society Advisory Group, Committee on Ethical and Societal Implications of Advances in Militarily Significant Technologies that are Rapidly Changing and Increasingly Globally Accessible; Computer Science and Telecommunications Board, The National Academies: National Research Council and National Academy of Engineering, Washington, D.C.: The National Academies Press, 68-78. [www.nap.edu](http://www.nap.edu).
- Djapic, Vladimir, et al. 2015. "Optimizing the Human Element in the Age of Autonomy." 4-7 May 2015. Atlanta, GA: AUVSI Unmanned Systems.
- Duvall, Lt Col Lourdes M. 2015. "Accounting for Human Information Processing." In *Future Trends and US National Security*, by PhD, USAF, Retired, and Col Kathleen Mahoney-Norris, PhD, USAFR, Retired Lt Col John T. Ackerman, 71-95. Maxwell Air Force Base, Alabama: Air University Press - Air Force Research Institute.
- Edwards, John. 2005. *The Geeks of War - The Secretive Labs and Brilliant Minds Behind Tomorrow's Warfare Technologies*. New York: AMACOM.
- Endsley, Mica R. June 2015. *Autonomous Horizons - System Autonomy in the Air Force - A Path to the Future*. Volume I: Human-Autonomy Teaming, Office of the USAF Chief Scientist, Washington, D.C.: United States Air Force.
- Erlor, Alexandre. 2011. "Does Memory Modification Threaten Our Authenticity." *Neuroethics* (Springer) (4): 235-249. [springerlink.com](http://springerlink.com).
- Fields, Craig. 2016. *Summer Study on Autonomy*. Final, Pentagon, Washington, D.C.: Defense Science Board.

- Freedberg Jr., Sydney J. 2015. "Centaur Army: Bob Work, Robotics, & The Third Offset Strategy." *Defense News*. Washington, D.C.: Defense News, November 9. Accessed February 2, 2017. <http://breakingdefense.com>.
- . 2015. "Will US Pursue "Enhanced Human Ops?" DepSecDef Wonders." *Defense News*. Washington, D.C.: Defense News Online, December 14. Accessed February 2, 2017. <http://breakingdefense.com>.
- Galster, Scott M. May 2013. *Sense-Assess-Augment - A Taxonomy for Human Effectiveness*. Interim Report, Wright-Patterson Air Force Base, OH: Air Force Research Laboratory.
- Gay, Malcolm. 2015. *The Brain Electric: The Dramatic High-Tech Race to Merge Minds and Machines*. New York: Farrar, Straus and Giroux.
- Giordano, James. 2012. *Neurotechnology; Premises, Potential, and Problems*. Edited by James Giordano. Vols. Advances in Neurotechnology Ethical, Legal, and Social Issues. Boca Raton, FL: CRC Press.
- Giordano, James, PhD. 2010. "The Mechanistic Paradox: On the Need for the Reciprocity of Science, Technology, Ethics and Policy." *Synesis: A Journal of Science, Technology, Ethics, and Policy* 1 (1): G1-G3.
- Glannon, Walter. 2006. "Neuroethics Responsibility." *Bioethics* (Blackwell) 20 (1): 37-52.
- Glannon, Walter. 2008. "Psychopharmacological Enhancement." *Neuroethics* (Springer) 1 (1): 45-54.
- Gonzales, Daniel, Sarah Harting. 2014. *Designing Unmanned Systems with Greater Autonomy: Using a Federated, Paritally Open Systems Architecture Approach*. Final, National Defense Research Institute, Santa Monica, CA: RAND Corporation. [www.rand.org](http://www.rand.org).
- Greene, Joshua D. 2014. "Beyond Point-and-Shoot Morality: Why Cognitive (Neuro) Science Matters for Ethics." *Ethics* (University of Chicago Press) 124 (4): 695-726.
- Hagel, Chuck. 2014. "Reagan Natinal Defense Forum Keynote." *Security Forum*. Simi Valley, CA: Ronald Reagan Presidential Library, November 15.
- Hagel, Chuck, Secretary of Defense. 2014. "The Defense Innovation Initiative." *Secretary of Defense*. Pentagon, Washington, D.C.: Office of the Secretary of Defense, November 15.
- James, Deborah Lee. September 2015. *Air Force Future Operating Concept*. Pentagon, Washington, D.C.: United States Air Force.
- James, Deborah Lee. July 2014. *America's Air Force: A Call to the Future*. Pentagon, Washington, D.C.: United States Air Force.
- James, Deborah Lee. 10 February 2016. *Fiscal Year 2017 Air Force Posture Statement*. Pentagon, Washington, D.C.: United States Air Force.
- Keebler, Joseph R., et al. 2012. "Neuroethics: Considerations for a Future Embedded with Neurotechnology (Chapter 13)." In *Neuroadaptive Systems - Theory and Applications*, by Magdalena, et al. Fafrowicz, 333-350. Boca Raton: CRC Press (Taylor & Francis Group).
- Kendall, Frank. 2014. "Long Range Research and Development Plan (LRRDP) Direction and Tasking." *Acquisiton Technology and Logistics*. Pentagon, Washington, D.C.: Under Secretary of Defense, October 29.

- Kollek, Regine. 2004. "Mind Metaphors, Neurosciences and Ethics." In *The New Brain Sciences - Perils and Prospects*, by Dai Rees and Steven Rose, 71-87. Cambridge, UK: Cambridge University Press.
- Kraemer, Felicitas. 2011. "Authenticity Anyone? The Enhancement of Emotions via Neuro-Psychopharmacology." *Neuroethics* (Springer) (4): 51-64. [springerlink.com](http://springerlink.com).
- Kraemer, Felicitas. 2013. "Me, Myself and My Brain Implant: Deep Brain Stimulation Raises Questions of Personal Authenticity and Alienation." *Neuroethics* (Springer) (6): 483-497. [springerlink.com](http://springerlink.com).
- Kuznar, Lawrence A. 2011. *From the Mind to the Feet - Assessing the Perception-to-Intent-to-Action Dynamic*. Maxwell Air Force Base, Alabama: Air University Press - Air Force Research Institute.
- Levy, Neil. 2008. "Introducing Neuroethics." *Neuroethics* (Springer) 1 (1): 1-8.
- Linderman, Michael D., et al. 2008. "Signal Processing Challenges for Neural Prostheses: a review of state-of-the-art systems." *IEEE Signal Processing Magazine*, January: 18-28.
- Masiello, Thomas J., Major General. 2 December 2013. *Air Force Research Laboratory Autonomy Science and Technology Strategy*. Wright-Patterson AFB OH: Air Force Research Laboratory.
- McAfee, Erik Brynjolfsson and Andrew. 2014. *The Second Machine Age - Work, Progress, and Prosperity in a Time of Brilliant Technologies*. New York: W. W. Norton & Company, Inc.
- McCarty, Kristin. 2014. "Building a Better Soldier: Human Enhancement Technologies in the 21st Century." *Paideia*, Inaugural Issue ed. doi:10.15368/paideia.2014v1n1.1.
- Miranda, Robbin A., et al. 2014. "DARPA-funded efforts in the development of novel brain-computer interface technologies." *Journal of Neuroscience Methods* (Elsevier B.V.) (244): 52-67. doi:[www.elsevier.com/locate/jneumeth](http://www.elsevier.com/locate/jneumeth).
- Moeller, Michel R., Lieutenant General. 2014. *Air Force Strategic Environment Assessment 2014-2034*. Pentagon, Washington, D.C.: United States Air Force.
- Moreno, Jonathan D. 2006. *Mind Wars: Brain Research and National Defense*. New York: Dana Press.
- Nagel, Saskia K. 2014. "Enhancement for Well-being is Still Ethically Challenging." Edited by Mikhail Lebedev. *Frontiers in Systems Neuroscience* (Frontiersin) 8 (72): 1-4. [www.frontiersin.org](http://www.frontiersin.org).
- O'Connel, Mary Ellen. 2014. "Banning Autonomous Killing (Chapter 12)." In *The American Way of Bombing*, by Matthew Evangelista, 224-299. Ithaca: Cornell University Press.
- Roebuck, Kevin. 2011. *Brain-Computer Interface: High-Impact Emerging Technology - What You Need to Know: Definitions, Adoptions, Impact, Benefits, Maturity, Vendors*. LaVergne, Tennessee, USA: Lightning Source.
- Sajda, Paul, et al. 2008. "Brain-Computer Interfaces." *IEEE Signal Processing Magazine*, January: 16-17.
- Schaefer, G. Owen, Guy Kahane and Julian Savulescu. 2014. "Autonomy and Enhancement." *Neuroethics* (Springer) (7): 123-136. [springerlink.com](http://springerlink.com).

- Scharre, Michael C. Horowitz and Paul. March 2015. *Meaningful Human Control in Weapon Systems: A Primer*. The Ethical Autonomy Project (20YY Warfare Initiative - Working Paper), Washington, D.C.: Center for a New American Security.
- Scharre, Paul. 2014. *Robotics on the Battlefield Part II: The Coming Swarm*. Washington, D.C.: Center for a New American Security.
- Schermer, Maartje, and Reinoud de Jongh, and Berend Olivier Ineke Bolt. 2009. "The Future of Psychopharmacological Enhancements: Expectations and Policies." *Neuroethics* (Springer) (2): 75-87. [springerlink.com](http://springerlink.com).
- Scientist, Office of the US Air Force Chief. 2011. *Technology Horizons - A Vision for Air Force Science and Technology 2010-30*. Maxwell Air Force Base, Alabama: Air University Press - Air Force Research Institute.
- Scott, Kevin D., Vice Admiral. 14 July 2016. *Joint Operating Environment 2035*. The Joint Force in a Contested and Disordered World, Pentagon, Washington, D.C.: Chairman of the Joint Staff.
- Tieu, Matthew. 2009. "Neuroethics." *Issues* 86: 20-23.
- Trzopek, Joanna, et al. 2012. "Psychological Constructs versus Neural Mechanisms: Different Perspectives for Advanced Research of Cognitive Processes and Development of Neuroadaptive Technologies." In *Neuroadaptive Systems Theory and Application*, by Magdalena, et al. Fafrowicz, 3-31. Boca Raton: CRC Press (Taylor & Francis Group).
- Welsh III, Mark A., General. 2014. *A Vision for the United States Air Force*. The World's Greatest Air Force - Powered by Airmen, Fueled by Innovation, Pentagon, Washington, D.C.: United States Air Force.
- Welsh III, Mark A., General. 2014. *Global Vigilance, Global Reach, Global Power for America*. The World's Greatest Air Force - Powered by Airmen, Fueled by Innovation, Pentagon, Washington, D.C.: United States Air Force.
- Work, Bob, interview by DoD News, Defense Media Activity Cheryl Pellerin. 2016. *Deputy Secretary Discusses Third Offset, First Organizational Construct* (September 21).
- Work, Bob, Deputy Defense Secretary. 2015. "The Third U.S. Offset Strategy and Its Implications for Partners and Allies." *Defense Policy Forum*. Willard Hotel, Washington, D.C., January 28.
- Zacharias, Greg L., PhD, SES, Chief Scientist of the Air Force. 19 November 2015. "Testimony: Advancing the Science and Acceptance of Autonomy for Future Defense Systems." *United States Congress, House Armed Services Committee*. Washington, D.C.: Subcommittee on Emerging Threats and Capabilities. 14.